Results from a portable Adaptive Optics system on the 1 meter telescope at the Naval Observatory Flagstaff Station

Sergio R. Restaino, G. Charmaine Gilbreath, Don M. Payne[1], J.T. Baker[2], T. Martinez[3], M. DiVittorio[4], David Mozurkewich, J. Friedman[5]

Naval Research Laboratory, Code 7215, Washington, DC 20375 USA

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ABSTRACT

In this paper we present results using a compact, portable adaptive optics system. The system was developed as a joint venture between the Naval Research Laboratory, Air Force Research Laboratory, and two small, New Mexico based-businesses. The system has a *footprint* of 18x24x18 inches and weighs less than 100 lbs. Key hardware design characteristics enable portability, easy mounting, and stable alignment. The system also enables quick calibration procedures, stable performance, and automatic adaptability to various pupil configurations. The system was tested during an engineering run in late July 2002 at the Naval Observatory Flagstaff Station one-meter telescope. Weather prevented extensive testing and the seeing during the run was marginal but a sufficient opportunity was provided for proof-of-concept, initial characterization of closed loop performance, and to start addressing some of the most pressing engineering and scientific issues.

1. Introduction

Results are presented from a compact, portable Adaptive Optics (AO) system. The AO system was developed as a joint venture between the Naval Research Laboratory (NRL), Air Force Research Laboratory (AFRL), and two small, New Mexico-based businesses: Baker Adaptive Optics (BAO) and Narrascape. The initial results presented in this paper show data from a system whose design approach views the AO system as a self-contained instrument much like a camera or a spectrograph rather than as a part of the infrastructure of the telescope, which is the traditional view. The goal of this ongoing work is to create a versatile, accessible approach for various current users and various new users of adaptive optics technologies and those investigators interested in improving the response of their telescopes by correcting the effects of the atmosphere. Of specific interest, is the development of a compact, lightweight, low cost AO system that can be deployed on multiple telescopes configured as an interferometer.

This system is characterized by flexibility and robustness that allows portability, simple mounting; ease of alignment and calibration procedures; and adaptability to readily exchange different types of Deformable Mirrors (DM) and wavefront sensors. Customized software and hardware combined with commercially available optics, camera, DM, and wavefront sensor provided a low cost, compact alternative to conventional systems.

[1] Narrascape, 3101 Hyder SE, Albuquerque NM 87106 USA
[2] Baker Adaptive Optics, 1155 Sandia Dr, Albuquerque NM 87068 USA
[3] Air Force Research Laboratory, Directed Energy Directorate, KAFB NM 87117 USA
[4] US Naval Observatory Flagstaff Station Flagstaff AZ USA
[5] University of Puerto Rico, Mayaguez, Puerto Rico

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14. ABSTRACT

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2. Experiment

The AO system was tested during an engineering run in July 2002 using the one-meter telescope at the Naval Observatory Flagstaff Station (NOFS) as shown in Figure 1. The observing run was during monsoon season. Although the seeing was poor, it was sufficient to test the optical layout and the closed loop performance of the software. Data were taken on Vega (alpha Lyae) between clouds and through haze during two nights. In the middle of the first night, the AO system was removed and a CCD camera was placed in the focal plane of the telescope optics train in order to calibrate the system using a standard NOFS camera. The AO system was then reinstalled.

The adaptive element used in this experiment was a MEMS 37-element mirror from OKO. The unit is 15 mm diameter and was driven with custom electronics to drive each pixel with 0V-140V providing a "throw" of approximately 60 waves (at 633 nm) for focus and about 2-1/2 waves for higher order corrections. Real-time data acquisition and control interfaces for the unit was provided by BAO and reconstructor and control algorithms were developed by Narrascape for PC-based control. The DM and ancillary electronics are shown in Figure 2.

The wavefront sensor was of a Shack-Hartman design coupled to a 128 pixel square Dalsa CCD camera. The hardware can support frame rates up to 800 per second. Since the camera's read noise limited performance, an image intensifier will be added for future observations. Combined with the poor seeing conditions, due in large part to high clouds on the one available night during the run, the performance of the Dalsa in this mode required actual frame rates to be around 100 Hz. For a brief period of time during the observing run the weather cleared enough to close the loop on the bright star Vega. For this run, the "science camera" used was a simple video camera running at 30 frames per second data rate.

The telescope itself presented a challenge to the wavefront reconstruction algorithm. The flat secondary on this telescope produces an unusually large central obstruction of 45%. Sixty subapertures were used for wavefront sensing. The wavefront reconstructor requred at least three subapertures between the inner and outer radii. Figure 3 shows both the pupil and the images formed by the subapertures. The 45% obscuration by the secondary is evident in both images.

The system was mounted on an 18x24 inch, .75 inch thick aluminum plate. The optics reside on top of the plate while the power supply and computer are mounted to the bottom of the plate. Heat dissipation was not addressed but does not appear to be an issue. Vibration from the computer's disk driver was suppressed by wrapping it in a vibration damping foam. The optical design was optimized for a compact system using ZeMax.

3.Results and Discussion:

Scintillation and poor seeing decreases the stability of the wavefront reconstruction since the variation in intensity makes for large differences in the signal-to-noise ratio from one sub-pupil to another. Cloud cover made observations logistically challenging. Images of Vega using open and closed loop corrective optics are shown in Figures 4a and 4b. The images are 30 second integrations. The closed-loop point spread function (PSF) is symmetric and the central peak is much higher. A different representation is shown in Figure 5. Open-loop Strehl was about 3.7% and Closed-loop Strehl was 22%, showing a factor of 6 improvement, even with the difficult conditions. A scan through an averaged frame is shown in Figure 6 demonstrating quantitively the difference between encircled energies recovered in open and closed loop conditions.

4. Applicability to Interferometry:

This AO system is being tested for applications on an interferometer where correction of higher orders is sought to improve the sensitivity of the instrument. In these data, the OKO mirror was fully taxed by the seeing conditions but if all 37 elements are used, on the order of 15 to 20 Zernike orders can be corrected.

A simulation of two-beam interferometer with telescope diameters much greater than r0 is shown in Figure 7. In this figure, fringe visibility, the interferometer's figure-of-merit, is plotted for varying degrees of AO c correction. This suggests that for a given set of conditions the AO should accommodate Zernike orders on the order of 10 to be effective. Our system clearly shows that it can accommodate such requirements under non-optimal atmospheric conditions.

5. Summary and Conclusion

The first test run of a portable adaptive optics system was performed. Mounting of the instrument, alignment, and "closing of the loop" on the system was accomplished in less than two days. Weather prevented substantial testing, however, the cloud cover opened long enough to "close the loop" on the Vega. Examples of this data have been presented with a 4 to 6 fold increase in Strehl . The paper shows that successful demonstration of the instrument concept and design was achieved. Important parameters such as size, weight, and ease of installation as well as performance also are important for applicability to interferometry where installation on a number of telescopes is needed to obtain viable images. We have shown that the compact system can be installed quickly on a one-meter telescope and produce viable images even in challenging weather conditions.

9. References

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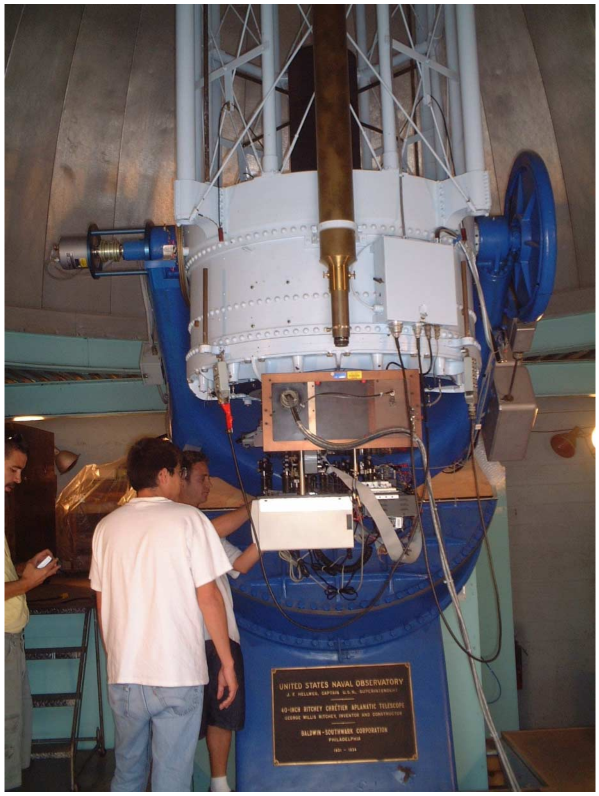


Figure 1. Compact Adaptive Optics system being installed on one-meter telescope at the Naval Observatory Flagstaff Station.

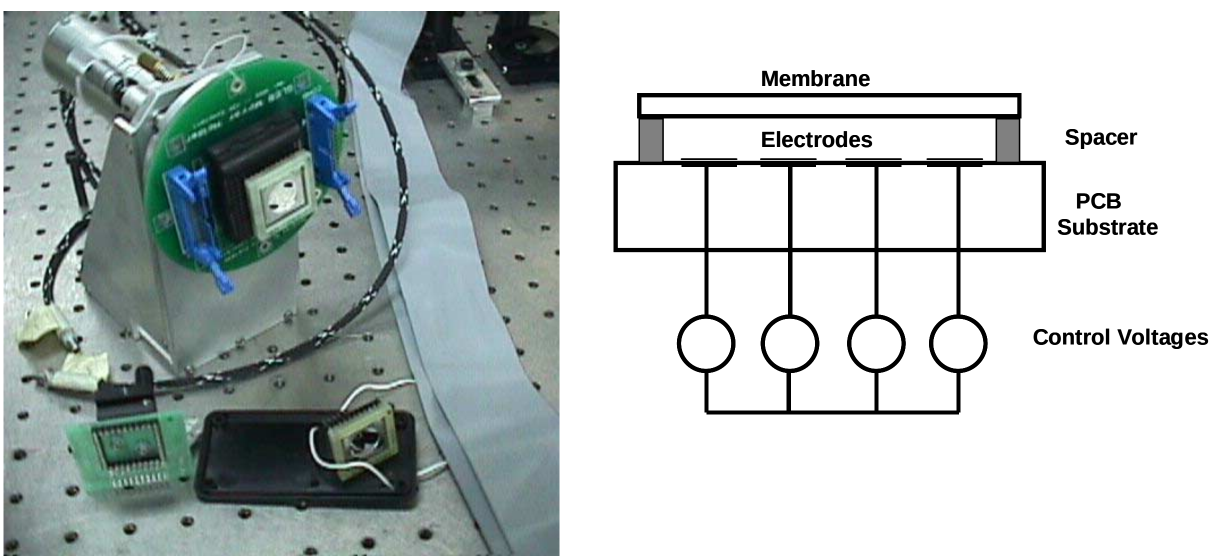
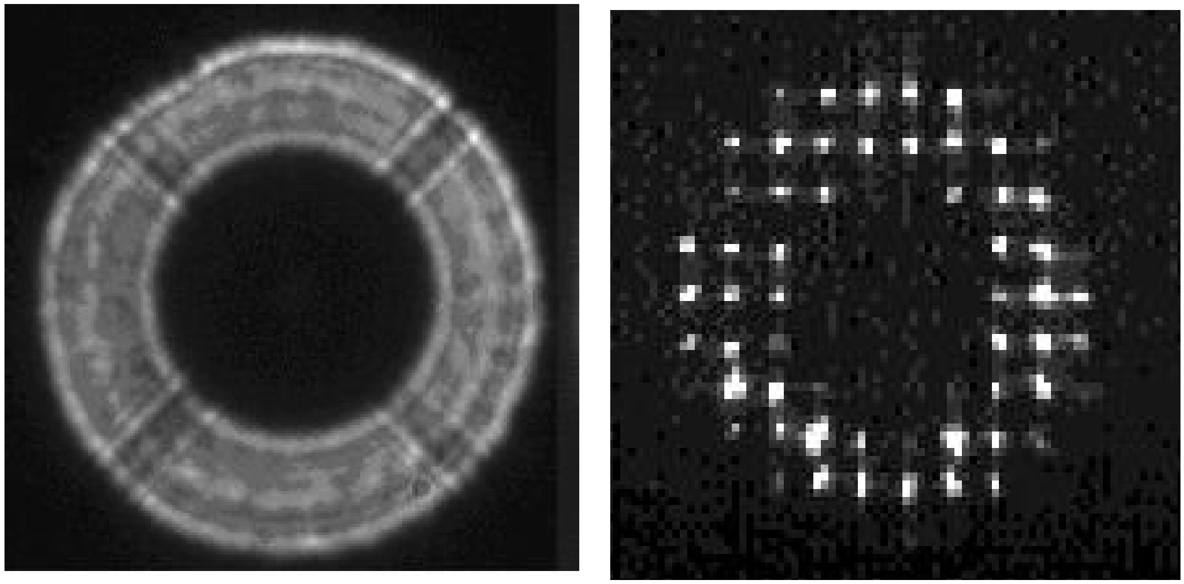
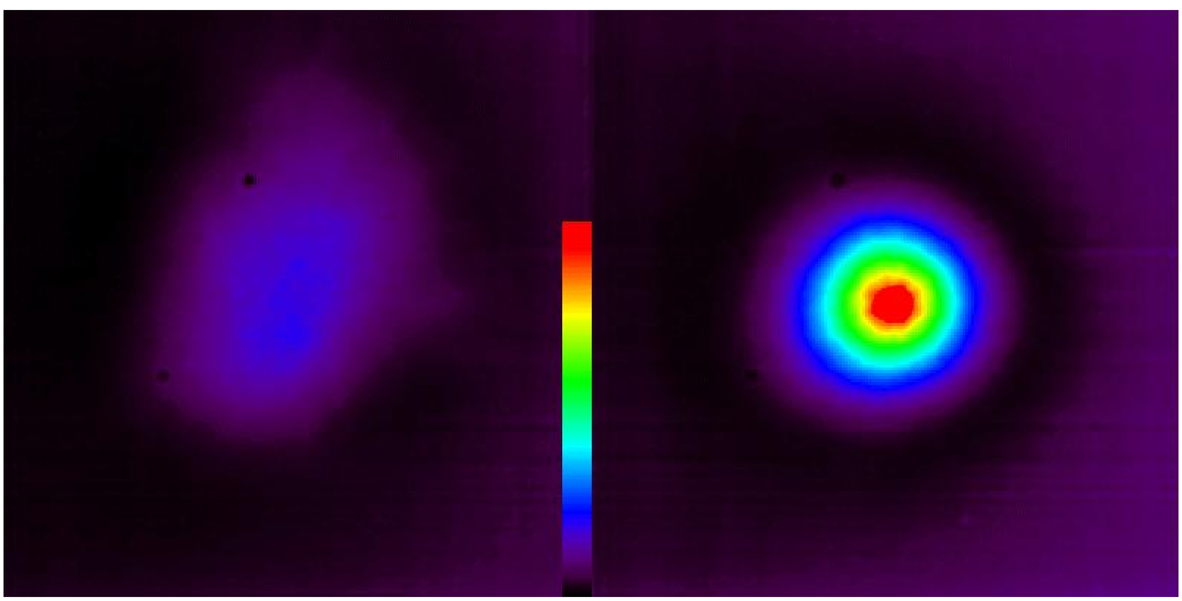


Figure 2. Photo and schematic of OKO deformable mirror used in described adaptive optics system. This unit has 37 active elements and measures 15 mm in diameter. Custom electronics drove the actuators.



(a) (b)

Figure 3. (a) Pupil imaged; large secondary evident as well as scintillation; (b) No. of pixels illuminated for wavefront correction.



(a) (b)

Figure 4. Vega imaged on a night with challenging seeing conditions with 30 seconds of frame integration: (a) Open loop; (b) Closed loop.

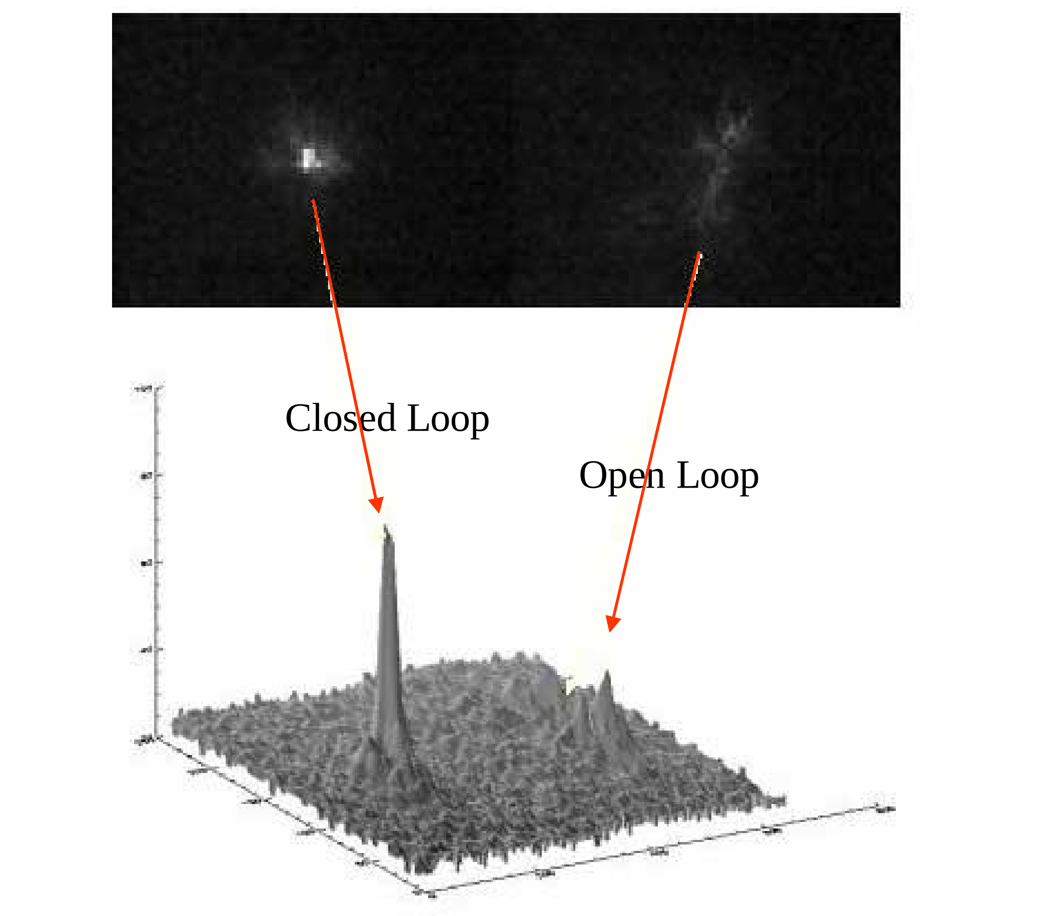


Figure 5. Image of Vega and Strehl compared between open and closed loop conditions.

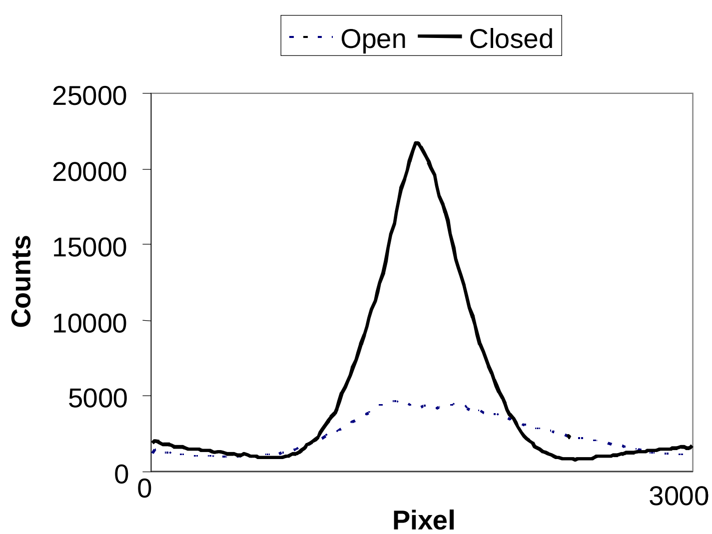


Figure 6. A "slice" through the averaged frames is shown here for closed and open loop conditions.

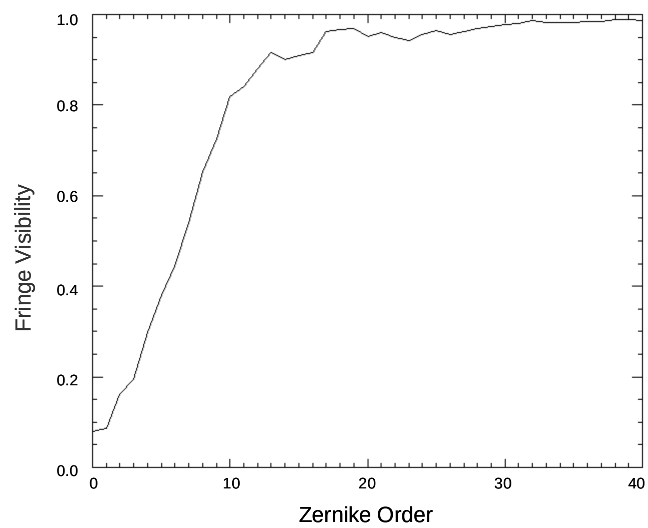


Figure 7. Fringe visibility vs. Zernike Order is shown. Graph indicates that AO correction of at least 10 Zernike modes are needed to obtain over 90% visibility. The unit tested produced these results.